The Influence of Statistical Regularities on the Spatial Congruency Bias

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by

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Introduction:

In order to recognize objects in space, visual features such as shape, color, size and location, must be integrated. However, these different modalities are represented in separate feature maps in the brain (Treisman, 1996), and must somehow be bound together. This process, commonly referred to as the 'binding problem,' allows us to distinguish between objects (Tresiman, 1996). In particular, location binding refers to the linking of object and location information processed in the ventral and dorsal pathways (commonly referred to as the 'what' and 'where' pathways, respectively) (Treisman, 1996; Mishkin et al., 1983).

Previous studies investigating the binding of object features to location have posited that location plays a unique role in the binding process. Kahneman et al. (1992) theorized that object information is temporarily addressed to a specific location in what is termed an 'object file.' This model presents location as a dominant feature to which object perception is linked. Such dominance of location in object perception may be attributed to the automaticity of location processing. For example, Johnston and Pashler (1990) show that location perception is a necessary precursor for identity perception, but location can be perceived even without identity perception.

The idea that location processing is automatic has implications for how we search for and define an object in space. Tsal and Lavie (1988) and Chen (2009) show that, even when task irrelevant, subjects maintain increased sensitivity to a target's location. As such, selection of an object feature may be mediated by increased sensitivity to its location in space (Tsal & Lavie, 1993; Cave & Pashler, 1995). Together, these studies present a view of location processing as automatic and integral to object perception.

The automaticity of location processing can lead to illusory conjunctions, wherein the feature of one object falsely characterizes another (Treisman, 1996). Recently, Golomb et al. (2014) discovered a "spatial congruency bias," or a tendency to report objects as the same if they are presented at the same location. This bias may be a product of illusory conjunctions, as the shared location of two objects falsely characterizes the identity of the second object. These findings reaffirm the privileged role of location in object recognition, and further explore the consequences of the prioritization of location over other object features.

Golomb et al. (2014) speculated that this spatial congruency bias might have evolved in order to take advantage of regularities in our environments; in the real world, objects in the same location tend to be the same identity. Therefore, the spatial congruency bias may be a phenomenon driven by years of prior exposure to these regularities in the world. However, the question remains of how robust this bias is. Since the automaticity of location processing in object recognition is well established, is this bias just a product of location dominance? Otherwise, if the spatial congruency bias is borne of regularities in the environment, could the bias then be malleable to changes in environmental regularities?

To investigate the flexibility of the spatial congruency bias, we consider statistical learning. In their review, Perruchet and Pacton (2006) present implicit learning and statistical learning as intrinsically related, wherein we may implicitly form chunks of information inferred from statistical computations about our environment. This model has direct implications for the spatial congruency bias, which may be a method of chunking information based upon location regularities in our environment. As such, if we are exposed to new regularities in the environment, it is possible that we may learn to chunk information in a new manner.

Turk-Browne et al. (2005), further discuss statistical learning from the perspective of vision. In their paper, they present visual statistical learning as automatic and implicit, provided that attention to stimuli is task-relevant (Turk-Browne et al., 2005). Therefore in our current study, we seek to exploit visual statistical learning in order to challenge the spatial congruency bias.

Current Study:

In the study by Golomb et al. (2014), subjects were presented with two objects sequentially, then asked to report if the objects were of the same or different identity. When faced with this task, subjects were more likely to report objects as having the same identity when they were presented at the same location. In reality, objects were equally likely to be of the same or different identity, regardless of their location. In our study, we sought to test the robustness of this bias by presenting subjects with opposing statistical regularities. Specifically, in trials where objects were presented at the same location, objects would have different identities in 75% of trials. Meanwhile in trials where objects were presented at different locations, objects would have the same identity in 75% of trials.

If the spatial congruency bias continues to be present under these conditions, it would reaffirm the dominant role of location in object perception and suggest that the bias is beyond the influence of novel statistical regularities presented within a single experimental session. Meanwhile if the bias is lost, this would indicate learned associations could override the bias.

To preview our results, despite these strong opposing regularities, subjects in Experiment 1 persisted in demonstrating a spatial congruency bias. Even when counterproductive to the task, they were still more likely to report objects at the same location as having the same identity. These results suggest: (1) the spatial congruency bias is resistant to newly learned associations, or (2) our manipulation was not strong enough to overcome the bias. To further examine these results, we performed an additional two experiments.

In Experiment 2, we sought to find if the results of Experiment 1 would persist even with more easily discriminable stimuli, as easier stimuli may make the opposing statistical regularities more obvious. Critically, Experiment 2 also included intermixed 'control' trials wherein no second image was presented, but subjects still had to make identity judgments. These control trials were intended to serve as an implicit test for learned associations about the opposing regularities.

Experiment 3 was modified directly from Experiment 1. This time, subjects were explicitly informed of the manipulation of trial conditions. This final experiment served as an extreme manipulation; if the spatial congruency bias persisted even under these conditions, it may truly be impossible to overcome it in an experimental setting.

General Method:

Methods for all three experiments were preregistered on the Open Science Framework (https://osf.io/ts5h9/?view_only=22e91c5bfaad4cb0968977ec9768b02e) prior to data collection. This includes method of participant recruitment, target sample size, exclusion criteria, experimental stimuli, task design and procedure, and main analysis methods. Additional analyses will be declared exploratory.

Subjects: As described in our preregistration, participants were recruited through the Research Experience Program at The Ohio State University, through which they received course credit for their participation. All subjects provided informed consent according to The Ohio State University Institutional Review Board, and reported normal or corrected-to-normal vision. Subject demographics are provided for each experiment below.

Experimental Setup: Stimuli were presented using MATLAB with the Psychtoolbox extension (Brainard, 1997) on a 21-in flat screen CRT monitor. Subjects were seated at a chinrest 60cm from the monitor (Experiments 1 and 2) or 65cm from the monitor (Experiment 3). Difference in chinrest distance was due to changes in testing room setup.

Eye Tracking: Eye position was monitored with an EyeLink 1000 eye-tracking system at a sampling rate of 500 Hz for each of the three experiments. Eye-tracking ensured that fixation on a central cross was maintained for the duration of each trial. If eye position escaped 2° of the central cross at any point during a trial, the trial was not included in analysis.

Stimuli: Stimuli were the same novel object morphs used in Golomb et al. (2014). As described in that paper, objects were modified from the Tarr stimulus set (stimulus images courtesy of Michael J. Tarr, Center for the Neural Basis of Cognition and Department of Psychology, Carnegie Mellon University, http://www.tarrlab.org). Ten object pairs were chosen in Golomb et al. (2014), and a morph series was created for each pair using FantaMorph software (Abrosoft; http://www.abrosoft.com). Each of these 10 families contained 20 individual exemplar objects (5% morph difference between each image). Within a family, the "body" of the object always remained constant, while the "appendages" could vary in shape, length, or relative location.

Within each family of objects, the first and twentieth objects were the most different from each other. From each of the 10 families, we selected the first and twentieth objects to form an object pair, as used in Experiments 1 and 3. (See Figure 1 for sample images.) We chose to use these stimuli based upon staircasing results from Golomb et al. (2014). In that study, stimuli differences were staircased such that each subject maintained 70-75% accuracy on the task. However as most subjects reached near maximum difference (first and twentieth objects), we decided to use these objects as pairs for all subjects in our study. In Experiment 2 the same stimuli were used, but object pairs were arbitrarily rearranged to come from two separate morph families. This alteration was intended to make an easier perceptual task, and the experimental regularities more obvious.

Stimuli were presented on a white screen. In Experiments 1 & 2, stimuli were sized 6.25° x 6.25°, centered at 7.07° eccentricity. In Experiment 3, stimuli were sized at 5.88° x 5.88°, centered at 6.66° eccentricity (difference due to changes in testing room setup).

Task and design: Experimental design was similar across experiments, with some variation. Trials began with a fixation-cross presented at the center of the screen (see Figure 2). After 500 ms, an object was presented at one of four possible locations on the screen (top right, top left, bottom right, or bottom left) for 500 ms. The object then disappeared (50 ms), followed by a black square mask (100 ms). After a delay of 1000 ms, the second object was presented for 500ms. The second object could have been presented at either the same or different location, and been of the same or different identity. If the object were of a different identity, it would be the corresponding object pair from the same morph family (Experiments 1 & 3), or an object from a different family (Experiment 2). The second object then disappeared (50 ms), followed by a black square mask (100 ms).

Subjects then completed a two-alternative forced-choice task, where they were prompted to respond whether the identity of the two objects was the same or different. Responses were recorded through keyboard buttons ('s' for same and 'd' for different). After responding, subjects received feedback if their response was correct or incorrect. If the subject's eyes had deviated from the fixation cross at any point during the trial, they were informed of the error instead of being prompted to respond. After an intertrial interval of 1000 ms, the next trial began.

There were four possible conditions: same identity objects at the same location (SISL), same identity objects at different locations (SIDL), different identity objects at the same location (DISL), and different identity objects at different locations (DIDL). In the first experiment of Golomb et al. (2014), these conditions were equally represented (25% of trials each). In the current series experiments, we manipulated the ratio of trial proportions such that conditions SIDL and DISL were more likely than conditions SISL and DIDL.

Analyses: We calculated each subject's reaction times (RTs) for each trial, as well as d' and response bias (criterion) measures, according to signal detection theory.

$$d' = z(\text{hit rate}) - z(\text{false-alarm rate})$$

$$\text{Response bias} = -(z(\text{hit rate}) + z(\text{false-alarm rate}))/2$$

Trials were excluded from analysis if RTs were greater than or less than 2.5 standard deviations of the respective subject's mean RT, or fixation deviated more than 2° from a central cross. Each of the three experiments had additional (1) accuracy requirements, and (2) minimum accepted trials for subject qualification (criterion set in advance through preregistration).

Planned two-tailed t tests and Cohen's d effect sizes were calculated for differences in response bias between conditions. Additionally, repeated-measures ANOVAs and partial eta squared effect sizes were calculated for reaction times, accuracy, and proportion 'same' responses.

Statistical Power: Our preregistered sample size was N = 16 subjects for each experiment. This sample size was chosen based on the power analysis of the spatial congruency bias paper by Bapat et al. (2017). The power analysis included a Cohen's d = 1.01 and a statistical power (1- β) of .96.

Experiment 1:

The first experiment in the study investigated the persistence of the spatial congruency bias by manipulating the ratios of trial conditions. Specifically, objects presented at the same location were more likely to be of a different identity, and objects at different locations were more likely to be the same identity. The goal of this manipulation was to find if statistical regularities of trial conditions could lead to implicit learning that would overcome the spatial congruency bias.

Methods:

Subjects: Twenty-two subjects participated in the experiment. Seven subjects were excluded from analysis due to lack of sufficient trials (< 240 trials), and one subject was excluded due to low overall accuracy (< 50%). Sixteen subjects were included in analysis (11 female, five male; mean age = 20.25; range: 18-38).

Task and design: In Experiment 1, conditions SIDL and DISL were more likely than conditions SISL and DIDL. Specifically, in a block of 24 trials, there were nine trials of SIDL (37.5% of trials), nine trials of DISL (37.5% of trials), three trials of SISL (12.5% of trials), and three trials of DIDL (12.5% of trials). These trial conditions were counterbalanced and randomly intermixed in each block.

In order for a subject's data to be included in analysis, they had to have completed a total of at least 240 accepted trials. (Trials with fixation errors or with RTs more than 2.5 standard deviations of a subject's mean RT were not accepted.) Due to this experiment's sensitivity to the distribution of trial types, trials with fixation errors were neither aborted nor repeated later in the block.

Subjects completed a practice block of 24 trials under supervision of the experimenter before beginning the experiment. During the practice block, subjects received immediate feedback if their eye position deviated from fixation with the presentation of a red X and abortion of the trial. After the practice block, subjects completed as many blocks of 24 trials as possible within the allotted 1-hr experimental session.

At the end of the experiment, subjects were posed with a series of post-questions to determine if they became aware of the experimental manipulation: (1) if they noticed any patterns in the experiment, (2) if objects were the same identity, were they more likely to be in the same or different location, and (3) if objects were a different identity, were they more likely to be in the same or different location. Subjects were then explicitly informed that objects at the same location were more likely to be different and objects at different locations were more likely to be the same. Subjects were then asked to freely respond (4) if in hindsight this manipulation seems accurate.

Results:

Mean proportions of 'same' identity responses were recorded for each of the four conditions: SISL, SIDL, DIDL, and DISL. As can be seen in Figure 3A, 'same' identity responses at the same location (SISL and DISL) were consistently higher than at different locations (SIDL and DIDL, respectively). Mean proportions for each subject were used to calculate response bias and d'. In addition to signal detection measures, we analyzed RT priming depending on location and identity conditions. Results for all experiments found in Table 1.

Bias: Figure 3B depicts the response bias for same and different location conditions. Here, a more negative value indicates a greater tendency to respond that items were 'same' identity, and a more positive value indicates a greater tendency to respond that they were 'different' identity. We performed one-sample t tests comparing same and different location bias to zero. Only same location bias had a significant bias, $t(15) = 4.21$, $p < 0.001$, $d = 1.49$, whereas different location bias did not, $t(15) = 1.45$, $p = 0.167$ $d = 0.51$. A paired-sample t test comparing between same and different location bias revealed a significant difference, $t(15) = 3.56$, $p < 0.005$, $d = 0.85$. This difference in bias indicates the presence of the spatial congruency bias.

Sensitivity: Calculation of d' revealed a significant effect of location, $t(15) = 4.01$, $p < 0.005$, $d = 0.41$, where sensitivity was greater for same than different location trials. (See Table 1 for repeated-measures ANOVA results.)

Priming: RT priming was significant for location, $F(1,15) = 11.83$, $p < 0.005$, $\eta_p^2 = 0.44$; objects presented in the same location had faster reaction times than those at different location. (See Table 1 for full repeated-measures ANOVA results.)

Learning Effect: An exploratory analysis included the separation of data by the first and second 150 trials, in order to investigate a potential learning effect. Two subjects were excluded from this analysis due to low trial count (< 300 trials). For each group of trials, we performed a paired t test comparing same location and different location biases. Here, a significant bias difference by location indicates the presence of the spatial congruency bias. The first 150 trials revealed a significant difference between same location bias (-0.531) and different location bias (-0.218), $t(13) = 3.69$, $p < 0.005$, $d = 1.09$. Similarly, the second 150 trials revealed a significant difference between same location bias (-0.244) and different location bias (0.074), $t(13) = 2.19$, $p < 0.05$, $d = 0.82$. Therefore, both groups of trials maintained a spatial congruency bias.

We then considered the difference in bias between the two groups of trials. We conducted a repeated-measures ANOVA of response bias with factors Location and Halves of trials. We did not find a significant interaction between Location and Halves of trials, $F(1,13) < 0.001$, $p = 0.98$, $\eta_p^2 = 0.00$. In summary, these analyses show that the spatial congruency bias continued to be significant during the second 150 trials of the experiment, and that there was no significant change in spatial congruency bias between halves.

Post-Questions: Responses to the post-questions suggest subjects did not become aware of the manipulation.

The first question asked if subjects noticed any patterns during the experiment. None of the participants correctly reported the manipulation of trial regularities.

The next questions asked (1) if objects were the same identity, were they more likely to be in the same or different location, and (2) if objects were a different identity, were they more likely to be in the same or different location. Of the 16 subjects, only four correctly reported different location and same location, respectively. However as these responses are at chance level (25%), they suggest subjects did not truly become aware of the manipulation.

The final question involved explicitly informing subjects of the manipulation, and asking if it seemed accurate in hindsight. Due to the subjective nature of this question, responses were varied (detailed in Table 2).

Discussion:

Experiment 1 aimed to investigate the persistence of the spatial congruency bias under opposing statistical regularities. Specifically, if objects were presented in the same location, 75% of the time they would be a different identity. Meanwhile if objects were in different locations, 75% of the time they would be the same identity. Despite these strong opposing regularities, results mirrored the findings of the first experiment of Golomb et al. (2014); subjects were still more likely to judge objects as having the same identity when they were presented at the same location. These results reaffirm the special role of location in object recognition, as the spatial congruency bias persisted even when detrimental to the task at hand. This further suggests that the bias may be beyond the influence of implicitly learned associations (i.e. opposing statistical regularities).

Additionally, in splits between the first and second 150 trials, there was still a significant spatial congruency bias in the second group of trials. This shows that even after 150 trials of exposure to the manipulation, location continued to bias subjects' responses.

Though Experiment 1 shows a persistence of the bias, it is unclear the extent to which subjects learned the manipulation (if at all). To address this question, we performed two additional experiments. Experiment 2 sought to replicate the findings of Experiment 1, with easier stimuli and a slightly different task design, to try to make the manipulation more obvious. Critically, Experiment 2 included the addition of control trials to test if the opposing regularities had been learned implicitly. Meanwhile, since implicit regularities in Experiment 1 were not enough to overcome the spatial congruency bias, Experiment 3 sought to find if explicit knowledge of the manipulation would overcome the bias.

Experiment 2:

Experiment 2 aimed to test the strength of the spatial congruency bias found in Experiment 1 with the use of easier stimuli. Specifically, morph object pairs from Experiment 1 were rearranged such that each pair included objects from two different morph families. The use of more easily differentiable stimuli was intended to make it easier for subjects to notice and learn the statistical regularities, which were the same as those present in Experiment 1 (objects at the same location were more likely to be different identity, and objects at different locations were more likely to be the same identity).

Experiment 2 also included control trials, wherein the second image in the task was not presented, yet participants were still asked to make same or different identity judgments as though it had been presented. We hypothesized that these control trials could serve as an implicit test for learned associations about statistical regularities. If subjects implicitly learned the new regularities, this may be reflected in their baseline bias when guessing during control trials.

With the addition of control trials, the experimental design is slightly different to that of Experiment 1. Therefore to ensure results were solely due to the manipulation of trial regularities, we conducted the experiment for two groups: one group with equal proportions of trial conditions (as in Golomb et al. (2014)), and one group with unequal proportions of trial conditions (as in Experiment 1).

Methods:

Subjects: Nineteen subjects participated in the group with equal proportions of trial conditions. Three subjects were excluded from analysis due to lack of sufficient trials (< 360 trials). Sixteen subjects were included in analysis (seven female, nine male; mean age = 19.44; range: 18-22).

Twenty-eight subjects participated in the group with unequal proportions of trial conditions. Eleven subjects were excluded from analysis due to lack of sufficient trials (< 360 trials). Seventeen subjects were included in analysis (eight female, nine male; mean age = 19.18; range: 18-21).

Task and design: Behavioral stimuli and task for Experiment 2 were similar to those of Experiment 1, with some changes.

Experiment 2 included control trials, wherein there was no second image presented, just a black square mask. In order to make the control trials less obvious, the second image in non-control trials was presented for a variable duration: randomly chosen between 500 ms (as in Experiment 1) or 50 ms. Thus, there were three possible stimulus durations for the second image: 500ms, 50ms, or 0ms (control trial). The trial progression was otherwise identical for all trials (see Figure 4 for full task design), and subjects were simply made aware that the second image would sometimes be presented very quickly, and they should make their best guess for the same/different identity task if they were unsure. Because the shortened presentation duration increased the difficulty of the task – and to make the stimuli more perceptually distinct in hopes of making the unequal-proportions manipulation more obvious – Experiment 2 also used easier stimuli (Figure 1). Rather than selecting morph object pairs from within the same family (as in Experiment 1), object pairs were selected from different families on different identity trials.

Additionally, Experiment 2 included two groups – one group with equal proportions of trial conditions, and one group with unequal proportions of trial conditions.

In each block, there were a total of 40 trials. In the group with equal proportions of trial conditions, there were eight trials for each of the four conditions (SISL, SIDL, DISL, and DIDL). For each of these conditions, half of the trials included a second image presented for 50 ms, and half included a second image presented for 500 ms. These trial conditions and timings were randomly counterbalanced within each block. The remaining eight trials were control trials; four had the second black mask presented in the same location as the first image, and four had it presented in a different location. In order to maintain the context of equal proportions, half of the control trials for each location condition were dummy-coded as same identity and half as different identity. Though there was no actual second image presented in control trials (just the mask), subjects still responded on each trial and received feedback after their response according to the dummy-coded proportions. Control trial conditions were randomly intermixed with standard trials throughout the experiment.

In the group with unequal proportions of trial conditions, there were four trials for conditions SISL and DIDL, and 12 trials for conditions SIDL and DISL per block. For each of these conditions, half of the trials included a second image presented for 50 ms, and half included a second image presented for 500 ms. These trial conditions and timings were randomly counterbalanced within each block. The remaining eight trials were control trials; four had the second black mask presented in the same location as the first image, and four had it presented in a different location. In order to maintain the unequal proportions, 75% of same location control trials were dummy-coded as different identity, and 75% of different location control trials were dummy-coded as same identity. Control trial conditions were randomly intermixed with standard trials throughout the experiment.

Feedback in Experiment 2 was slightly different to that of Experiment 1. Specifically, rather than simply being informed if they were correct or incorrect, subjects would be informed of the correct response as well (eg. "Correct, they were same," or "Incorrect, they were actually same"), in an attempt to further make the manipulation more obvious.

After initial instructions and a practice block of 40 trials (consisting of 500ms trials only, with no control trials), subjects were warned of varying trial times. They were informed that: "sometimes the second image will appear faster." Subjects then completed as many blocks of 40 trials of the main task as possible within the allotted 1-hr session. In order for a subject's data to be included in analysis, they had to have at least 50% accuracy, and complete at least 360 accepted trials. (Trials with fixation errors or with RTs more than 2.5 standard deviations of a subject's mean RT were not accepted.)

At the end of the experiment, subjects were posed with the same series of post-questions as in Experiment 1: (1) if they noticed any patterns in the experiment, (2) if objects were the same identity, were they more likely to be in the same or different location, and (3) if objects were a different identity, were they more likely to be in the same or different location. Subjects were also asked: (4) what their thoughts were on the difficulty of the experiment, and (5) if they noticed that on some trials there was no second image.

Results:

As in the first experiment, mean proportions of 'same' identity responses were recorded for each condition (SISL, SIDL, DISL, and DIDL), for each group of subjects (equal and unequal proportions). Trials were collapsed across second image presentation time (50ms or 500ms) due to similar results between these different trial types (see later section for full analysis).

Results from groups with equal and unequal trial conditions were similar. As can be seen in Figure 5A and Figure 5B, 'same' identity responses at the same location (SISL and DISL) were consistently higher than at different locations (SIDL and DIDL, respectively). As in Experiment 1, mean proportions for each subject were used to calculate response bias and d', and RT priming was analyzed depending on location and identity.

Bias: Figure 5C and Figure 5D depict the response bias for same and different location conditions in the groups with equal and unequal trial conditions, respectively. As before, a more negative value indicates a tendency to respond 'same' identity, and a more positive value indicates a tendency to respond 'different' identity.

For the group with equal trial conditions, we performed one-sample t tests comparing same and different location bias to zero. Only same location bias had a significant bias, $t(16) = 2.41$, $p < 0.05$, $d = 0.83$, whereas different location bias did not, $t(16) = 1.37$, $p = 0.190$ $d = 0.47$. T tests comparing between same and different location bias revealed a significant difference, $t(16) = 3.27$, $p < 0.005$, $d = 0.90$. The significant difference between same and different location bias indicates that the spatial congruency bias is present in this group with equal trial conditions.

For the group with unequal trial conditions, we again performed one-sample t tests comparing same and different location bias to zero. Both same location bias, $t(15) = 1.72$, $p = 0.106$, $d = 0.607$, and different location bias, $t(15) = 1.49$, $p = 0.158$ $d = 0.53$, were not significant. Critically however, t tests comparing between same and different location bias revealed a significant difference, $t(15) = 4.00$, $p < 0.005$, $d = 0.80$, showing that the spatial congruency bias was present in this group with unequal trial conditions as well.

Additionally to compare between groups with equal and unequal conditions, we performed a mixed ANOVA with a within-subjects factor of same and different location bias, and a between-subjects factor of group. We found a significant main effect of location, $F(1,31) = 24.54$, $p < 0.001$, $\eta_p^2 = 0.44$, indicating an overall spatial congruency bias, with no significant effect of group, $F(1,31 = 0.01$, $p = 0.92$, $\eta_p^2 = 0.00$, and no significant interaction between group and location bias, $F(1,31) = 0.08$, $p = 0.79$, $\eta_p^2 = 0.002$.

Control Trials: Because there were no actual hits or false alarms on control trials, we did not calculate bias, but simply compared the mean proportions of 'same' identity responses in the control trials for each location as a proxy for the spatial congruency bias. As can be seen in Figure 5E and Figure 5F, there was no clear difference of response depending on location. For the group with equal trial conditions, a paired t test revealed no significant difference between the proportion of 'same' responses in same and different location trials, $t(16) = 0.004$, $p = 0.997$, $d = 0.15$. Similarly for the group with unequal trial conditions, a paired t test revealed no significant difference between the proportion of 'same' responses in same and different location trials, $t(15) = 0.34$, $p = 0.742$, $d = 0.03$. To compare results between groups with equal and unequal trial conditions, we performed a mixed ANOVA with a within-subjects factor of same and different location proportion 'same' responses, and a between-subjects factor of group. We found no significant interaction between group and proportion 'same' responses, $F(1,31) = 0.04$, $p = 0.84$, $\eta_p^2 = 0.001$.

Sensitivity: For measures of sensitivity, we calculated d' using only non-control trials. In the group with equal trial conditions, calculation of d' did not reveal a significant effect of location, $t(16) = 1.24$, $p = 0.234$, $d = 0.15$. For the group with unequal trial conditions, there was also no significant effect of location, $t(15) = 1.87$, $p = 0.081$, $d = 0.17$.

Priming: For analysis of RT priming, we used only non-control trials. In the group with equal trial conditions, RT priming was significant for location, $F(1,16) = 9.50$, $p < 0.01$, $\eta_p^2 = 0.37$; objects presented in the same location had faster reaction times. In the group with unequal trial conditions, RT priming was not significant for location, $F(1,15) = 0.17$, $p = 0.69$, $\eta_p^2 = 0.01$. (See Table 1 for full repeated-measures ANOVA results.)

Presentation Time Effect: In the group with equal trial conditions, there was a significant difference in response bias between same and different location for both 500ms trials, $t(16) = 2.35$, $p < 0.05$, $d = 0.75$, and 50ms trials, $t(16) = 2.56$, $p < 0.05$, $d = 0.74$. A repeated-measures ANOVA did not find a significant effect of presentation time with factors presentation time and location bias, $F(1,16) = 4.08$, $p = 0.06$, $\eta_p^2 = 0.20$.

In the group with unequal trial conditions, there was a significant difference in response bias between same and different location for both 500ms trials, $t(15) = 3.74$, $p < 0.005$, $d = 0.99$, and 50ms trials, $t(15) = 3.09$, $p < 0.01$, $d = 0.54$. A repeated-measures

ANOVA did not find a significant effect of presentation time with factors presentation time and location bias, $F(1,15) = 1.99$, $p = 0.18$, $\eta_p^2 = 0.12$.

Despite the use of two different presentation times for the second image, presentation time did not significantly influence the location bias. In both groups, the spatial congruency bias was present in trials of both possible presentation times. Therefore, we chose to collapse trials across presentation time for above analyses.

Post-Questions: Responses to the post-questions suggest subjects did not become explicitly aware of the manipulations.

The first (intentionally vague) question asked if subjects noticed any patterns during the experiment. In the group with equal trial conditions, two of 17 subjects reported that some stimuli flashed too quickly. In the group with unequal trial conditions, two of 16 participants reported that in some trials there was only a black box (image mask).

The next question asked: if objects were the same identity, were they more likely to be in the same or different location. In the group with equal trial conditions, seven subjects said same location and seven subjects said different location. In the group with unequal trial conditions, five subjects said same location and six subjects said different location. The third question asked: if objects were a different identity, were they more likely to be in the same or different location. In the group with equal trial conditions, six subjects said same location and 11 subjects said different location. In the group with unequal trial conditions, three subjects said same location and 10 subjects said different location. Overall these responses suggest subjects did not become aware of the unequal-proportions manipulation, as responses did not vary between the two groups.

The fourth question asked what subjects thought about the difficulty of the experiment. In the group with equal trial conditions, four of 17 subjects reported that the faster trials were sometimes too hard or impossible. In the group with unequal trial conditions, four of 16 subjects reported some manner of difficulty during faster trials. These responses suggest that subjects may have become aware to some extent of the presence of the control trials (where no second image was presented).

The final question asked if subjects noticed that on some trials there was no second image. In the group with equal trial conditions, all 17 subjects reported that they noticed, but nine of these subjects also said they had assumed these trials were just too fast. In the group with unequal trial conditions, 14 of 16 subjects reported that they noticed, but five of these subjects said they assumed these trials were too fast. In summary, responses to this question suggest that while subjects may not have known with certainty that there was no second image in some trials, they were aware that they themselves had not perceived an object.

Discussion:

In Experiment 2, we sought to investigate (1) if the spatial congruency bias persists in the face of opposing statistical regularities even when the task stimuli were easier to differentiate, and (2) if the addition of control trials could serve as an implicit test for learned associations. In order to control for these new manipulations, Experiment 2 was conducted in two groups: one with equal trial conditions (as in Golomb et al. (2014)), and one with unequal trial conditions (as in Experiment 1 of this study).

This second experiment revealed a persisting spatial congruency bias in both experimental groups, despite the use of easier stimuli. This replication of findings from

Experiment 1 serves to reaffirm the robustness of the spatial congruency bias in the face of strong opposing statistical regularities.

Meanwhile, subjects also completed a set of intermixed control trials. During control trials, subjects did not receive identity information about a second object; instead, subjects only viewed a mask at the location of the second object. As a result, they were *only* privy to location information.

Results from control trials did not reveal a significant difference in response depending on location. Assuming control trials served as a test for implicitly learned associations, these results might suggest subjects did not learn to associate same location with different identity, and vice versa. However, another possibility is that the control trials were not effective measures of implicitly learned associations. In order to measure a learning effect, we must at least see a baseline congruency bias in the group with equal trial proportions. Therefore, while the control trials were not useful as a test for implicitly learned associations here, they proved to be valuable in a more general sense, providing evidence that the spatial congruency bias seems to be a perceptual phenomenon wherein subjects must actually perceive both objects in order for the bias to operate, rather than the bias reflecting some sort of decision-level implicit guessing strategy.

Experiment 3:

Experiment 3 was similar to Experiment 1 with the addition of explicit information about the skewed ratios of trial conditions. Here we sought to investigate the robustness of the spatial congruency bias in an extreme case where we know subjects have explicit knowledge of the statistical regularities.

If subjects maintained the spatial congruency bias even with explicit information, we expected results to mirror those of Experiments 1 & 2. However if subjects responded based off of their explicit knowledge instead, we expected to see a reverse in the bias, where subjects are more likely to respond "same" identity when objects are presented at different locations, and vice versa.

Methods:

Subjects: Twenty-six subjects participated in the experiment. Seven subjects were excluded from analysis due to lack of sufficient trials (< 360 trials), and three subjects was excluded due to low accuracy (< 50% for at least one condition). Sixteen subjects were included in analysis (nine female, seven male; mean age = 18.75; range: 18-21).

Task and design: Behavioral stimuli and task for Experiment 3 were the same as Experiment 1, with some changes.

After initial instructions and a practice block of 24 trials (same as Experiment 1), subjects were informed of the experimental manipulation (Figure 6A). Specifically, they were informed that when objects are in the same location, 25% would be the same identity, and 75% a different identity. Meanwhile when objects are in a different location, 75% would be the same identity, and 25% a different identity.

Subjects then completed a set of five 'test trials' to ensure they understood the manipulation (see Figure 6B). Test trials did not include actual objects; only black square masks were included as location cues. After the sequential presentation of two black masks, subjects were asked to report whether they were more likely to be of the same or different identity if they were actual objects rather than black masks (based upon the location of the masks and provided percentages). Subjects had to repeat this series of five trials until they answered all correctly. Two trials consisted of same location black masks (correct response: different identity), and three trials consisted of different location black masks (correct response: same identity).

Finally, subjects completed an additional practice block of 24 trials (same as before test trials). If subject accuracy noticeably declined during this second practice block, the experimenter would remind subjects that they should continue to respond as accurately as possible. This verbal instruction was intended to discourage subjects from responding solely based upon the provided percentages.

As in Experiments 1 & 2, subjects then completed as many blocks as possible within the allotted 1-hr session. In order for a subject's data to be included in analysis, they had to have completed at least 360 accepted trials. (Trials with fixation errors or with RTs more than 2.5 standard deviations of a subject's mean RT were not accepted.) Additionally, to avoid inclusion of subjects that responded solely based upon the provided percentages, subjects had to have at least 50% accuracy for each individual trial condition (SISL, SIDL, DISL, and DIDL).

At the end of the experiment, participants were asked (1) if they used any strategy during the experiment, and (2) if the information about percentages was helpful.

Results:

As in Experiment 1, mean proportions of 'same' identity responses were recorded for each of the four conditions (Figure 7A). However unlike Experiment 1, 'same' identity responses were only higher at the same location when object identity was actually same (SISL). When object identity was different, 'same' identity responses were higher for different location trials (DIDL). These proportions were used to calculate response bias and d' for each subject. We also analyzed RT priming depending on location and identity.

Bias: Figure 7B depicts the response bias for same and different location conditions. As in Experiment 1, a more negative value indicates a tendency to respond 'same' identity, and a more positive value indicates a tendency to respond 'different' identity. We performed one-sample t tests comparing same and different location bias to zero. Same location bias was not significant, $t(15) = 0.90$, $p = 0.384$, $d = 0.317$, whereas different location bias was significant, $t(15) = 3.02$, $p < 0.01$ $d = 1.07$. However, t tests comparing between same and different location bias did not reveal a significant difference, $t(15) = 1.23$, $p = 0.237$, $d = 0.52$, indicating there was no spatial congruency bias.

Sensitivity: Calculation of d' revealed a significant effect of location, $t(15) = 5.86$, $p < 0.00005$, $d = 0.58$, where performance was improved for same compared to different location trials.

Priming: RT priming was not significant for location $F(1,15) = 3.35$, $p = 0.09$, $\eta_p^2 = 0.18$, although numerically objects presented in the same location had faster reaction times. (See Table 1 for full repeated-measures ANOVA results.)

Learning Effect: An exploratory analysis (as in Experiment 1) included the separation of data by the first and second 180 trials, in order to investigate a potential learning effect. For each group of trials, we performed a paired t test comparing same location and different location biases. Here, a significant bias difference by location indicates the presence of the spatial congruency bias. The first 180 trials did not reveal a significant difference between same location bias (-0.531) and different location bias (-0.218), $t(15) = 0.64$, $p = 0.53$, $d = 0.27$. Similarly, the second 180 trials did not reveal a significant difference between same location bias (-0.244) and different location bias (0.074), $t(15) = 0.51$, $p = 0.62$, $d = 0.20$.

We then considered the difference in bias between the two groups of trials. We conducted a repeated-measures ANOVA of response bias with factors Location and Halves of trials. We did not find a significant interaction between Location and Halves of trials, $F(1,15) = 0.98$, $p = 0.34$, $\eta_p^2 = 0.06$. In summary, these analyses show that the spatial congruency bias was already insignificant during the first 180 trials of the experiment, and that there was no significant change in bias between halves. These results suggest that there was no learning effect between halves; rather, the loss of location bias was likely due to the adoption of an explicit strategy at the beginning of the experiment.

Post-Questions: Responses to post-questions suggest subjects were highly variable. The first question asked if subjects used any strategy during the experiment. Four of 16 subjects mentioned using the provided percentages; other responses were varied. Meanwhile the second question asked if subjects found the information about percentages helpful. Here, nine subjects reported that the percentages were helpful to some level, though with varying levels of conviction.

Due to the subjective nature of responses, post-questions were not used for further analyses. However, the large variability of responses alludes to the large variability within individual subjects.

Subject Distributions: As shown in earlier analysis, response bias was not significantly different between same and different location, making it difficult to draw conclusions on the main effect during Experiment 3. One potential explanation for this lack of significance is a mixed effect of the spatial congruency bias and explicit information.

In an exploratory analysis to quantify the distribution of subject performance, we calculated the "spatial congruency bias" for each subject as the difference in bias, subtracting the response bias for different location trials from response bias for same location trials for each subject. In Experiment 3, only five of 16 subjects showed a negative difference (indicating a spatial congruency bias). This contrasts with Experiment 1, where 13 of 16 subjects had a negative difference.

Figure 8 includes a histogram of the individual spatial congruency bias values (difference in bias measure) over all three experiments. It is clear that Experiments 1 & 2 are skewed negative (showing a reliable spatial congruency bias), whereas Experiment 3 shows a different distribution. Though bias differences were overall more likely to be positive in Experiment 3 (suggesting a reversed spatial congruency bias), these values are close to zero and resemble a null distribution. Together, these results suggest that subjects in Experiment 3 responded under a mix of influences: the spatial congruency bias and explicit information. Though subjects explicitly learned new regularities, the original bias was not completely reversed.

Discussion:

Experiment 3 sought to investigate the robustness of the spatial congruency bias under the influence of explicit information. We hypothesized that there were two possible factors that could influence subjects' responses: the spatial congruency bias and an explicit strategy. We did not consider implicit learning as a likely factor, as we would have seen it in Experiment 1 if it were present.

The addition of explicit information introduces potential effects of cognitive control, and could lead subjects to adopt a strategy based upon the provided percentages (intentionally responding same identity during different location trials, and different identity during same location trials). If subjects were influenced by explicit knowledge, we expected to see a reverse of the spatial congruency bias, wherein there is a significantly more negative response bias for different location trials compared to same location trials. On the other hand, if subjects completely ignored the explicit information, we expected to see a significantly more negative response bias for same location trials compared to different location trials (as in Experiments 1 & 2).

The results of Experiment 3 suggest a potential mix of both factors, where the typically negative spatial congruency bias was eliminated but not completely reversed. The results indeed reflect the influence of explicit knowledge, as the direction of response bias difference is consistent with the explicitly unequal task proportions. There was also a significantly negative response bias (more likely to respond same identity) for different location, which was not found in the prior experiments; while the response bias for same location (typically significantly negative) was eliminated. Nevertheless, if explicit strategy were the sole influence during Experiment 3, it is expected that the same location response bias would have become significantly positive, and the bias for different location trials would have been significantly more negative than bias for same location trials (i.e., a significant reversed spatial congruency bias). The lack of significant difference suggests that, rather than responding exactly based off of the explicit information, subjects may still have been somewhat influenced by the spatial congruency bias. These competing effects thus led to a less-pronounced effect of explicit knowledge.

An analysis of the difference in response bias between same and different location revealed a distribution centered near zero. Unlike Experiments 1 & 2 where the distributions were skewed left, these results reflect a mixed effect of the spatial congruency bias and explicit information. Though the explicit knowledge impacted responses, its influence was not enough to completely reverse the spatial congruency bias.

In summary, Experiment 3 did not show a significant difference in bias between same and different locations, demonstrating that subjects did adjust their behavior in response to explicitly learned regularities. However, the lack of significantly reversed difference in bias suggests that, even with an extreme manipulation, the spatial congruency bias is not completely bypassed.

General Discussion:

During object recognition, we must integrate different visual features in what is called the 'binding problem' (Treisman, 1996). Previous studies have shown that location has a privileged role during object feature binding. Specifically, Golomb et al. (2014) found a 'spatial congruency bias' wherein objects viewed at the same location were more likely to be reported as having the same identity.

In this study we sought to investigate the robustness of this spatial congruency bias by incorporating opposing statistical regularities in the task; objects presented in the same location were more likely to be of different identities, and objects presented at different locations were more likely to be of the same identity. These opposing statistical regularities were intended to test if subjects could implicitly learn new associations and overcome the bias.

Experiment 1 of our study was almost identical to the first experiment in Golomb et al. (2014). However, if objects were presented in the same location, 75% of the time they would be a different identity. Meanwhile if objects were in different locations, 75% of the time they would be the same identity. Despite this strong manipulation, results from this experiment mirrored those of Golomb et al. (2014). This suggests that the spatial congruency bias is even more robust than we had previously imagined. Even though it was counterproductive to the task, location continued to play a dominant role in object perception. Therefore in subsequent experiments, we sought to make the opposing statistical regularities even more obvious in order to test the bounds of the bias.

The second experiment of our study sought to make the opposing statistical regularities easier to learn by making the task itself easier. Specifically, we used stimuli that were more easily differentiable so as to minimize the attentional costs of completing the task. However despite the easier task, subjects maintained a significant spatial congruency bias, replicating results from Experiment 1 and reaffirming the dominance of location information in object perception.

Experiment 2 also included control trials, wherein subjects were not presented with a second image, and instead saw only a mask at the location of the second image. However, subjects were still forced to make same or different identity judgments. Here we sought to test if control trials could serve as an implicit test for learned associations. We hypothesized that if subjects implicitly learned the new regularities, this knowledge may be reflected in their responses when guessing during control trials. In other words, when the second mask was presented at a different location from the first image, there would be a larger proportion of 'same' responses when subjects were exposed to opposing statistical regularities. To ensure we had a proper baseline for these control trials, Experiment 2 was conducted in two groups: one with equal proportions of trial conditions, and one with unequal proportions (as in Experiment 1).

Results from the control trials showed no significant difference in responses between the group with equal proportions and the group with unequal proportions. These results suggest subjects may not have implicitly learned the opposing statistical regularities, or that this implicit knowledge did not influence task behavior. However, this logic relies on the assumption that the spatial congruency bias would present as an implicit strategy used when guessing, even in the absence of perceptible stimuli. Because no prior studies had ever tested this, we included the equal proportions group to establish a baseline. If the spatial congruency bias results in a biased guessing strategy on control (non-visible 2nd object) trials, we would expect responses to be biased accordingly, with more "same identity" responses for the same location control trials. However, in the group with equal proportions (where subjects were not exposed to the opposing statistical regularities), we did not find a baseline shift on the control trials.

The fact that neither group showed a significant difference in control trial responses by location suggests that the spatial congruency bias may actually be a perceptual phenomenon that requires the perception of an object in order for the bias to exist. These results reflect those of Experiment 3 from Golomb et al. (2014), which showed that the spatial congruency bias influences not only judgments of 'same or different' identity, but also judgments of similarity. In that experiment, subjects rated objects on a similarity index of: same, slightly different, or very different. When objects of a different identity were presented at the same location, subjects rated them as more similar than when they were presented at different locations. These prior findings present the spatial congruency bias as a process that occurs during perception, rather than at the response-level (Golomb et al., 2014). Therefore, results from our control trials serve to provide even stronger evidence that, aside from influencing perception of object identity, location information does not “override obvious identity information” (Golomb et al., 2014).

Finally, in Experiment 3 we sought to challenge the spatial congruency bias with an even more extreme manipulation. This final experiment was near identical to Experiment 1, though we provided subjects with explicit knowledge of the opposing regularities. Subjects were informed that if objects were in the same location, 75% of the time they would be a different identity; meanwhile if objects were in different locations, 75% of the time they would be the same identity.

Results from Experiment 3 reflect an influence of explicit knowledge, as there was indeed a loss of the spatial congruency bias; subjects were now more likely to report objects at the same location as having a different identity. However, if subjects were responding perfectly based upon the explicit information, we expected to see a full reversal of the bias. Yet results did not reveal a significant difference in bias between same and different locations. This pattern likely reflects a dual effect of perceptual judgments (influenced by spatial congruency bias) and explicit strategy. If subjects responded based upon their explicit knowledge but still retained the spatial congruency bias, a mixed influence of these two factors may have effectively cancelled out the effects of both.

Though our results suggest a dual effect of the original bias and explicit knowledge, these two factors may reflect different processes. Since subjects were provided with explicit knowledge of the task, they could utilize a strategy that bypasses their true perception of object identity. It is therefore difficult to separate such cognitive control processes from actual object recognition. As such, Experiment 3 serves as an interesting comparison to the first two experiments, but it is difficult to draw firm conclusions from this experiment alone about the robustness of the spatial congruency bias.

In summary, these three experiments reveal that strong opposing statistical regularities were not enough to overcome the spatial congruency bias, as subjects were not able to implicitly learn new associations. Only in Experiment 3, where subjects were explicitly informed of the regularities, was there a loss of the bias. But even there, the spatial congruency bias was not completely reversed. This suggests that exposure to opposing regularities in short experimental sessions – even with explicit knowledge – may not be enough to overcome years of experience that objects in the same location tend to be the same identity.

An interesting follow-up question would be whether more extended exposure to the opposing regularities, for example a multi-session or long-term study, would be more effective at challenging the spatial congruency bias. However, an alternative possibility is that even with more extensive exposure, visual statistical learning may not be as simple as anticipated. Turk-Browne et al. (2005) show that statistical learning only takes place when the stimulus is attended to. They further speculate that visual statistical learning may encode some stimulus properties over others (Turk-Browne, 2005). Therefore in our study, it may be the case that location information was not selectively attended to since (in Experiments 1 & 2) it was irrelevant to the task, making it impossible for subjects to implicitly learn the statistical regularities binding identity to location. As such, the previously established automaticity of location processing may involve different mechanisms from location processing as it pertains to statistical learning.

Another possible direction of future study includes exploring the origin of the spatial congruency bias from a developmental perspective. One explanation is that the spatial congruency bias originates from years of exposure to regularities in the real world (i.e. objects in the same location tend to be the same identity). Therefore, it would be interesting to perform this experiment in a younger population that may not have accumulated enough experience to develop the spatial congruency bias.

Alternatively, the spatial congruency bias may be a product of the way we process visual information in the brain. Di Lollo (2012) discusses how visual feature maps involved in binding are not necessarily encoded separately in the visual cortex. Therefore, the spatial congruency bias may be a result of object identity becoming distorted by object location represented in the same regions, in which case we might still expect to see a bias in young children. Research into the mechanisms behind this bias will allow us to better understand the way we perceive and interact with our physical environment.

Figures & Tables:

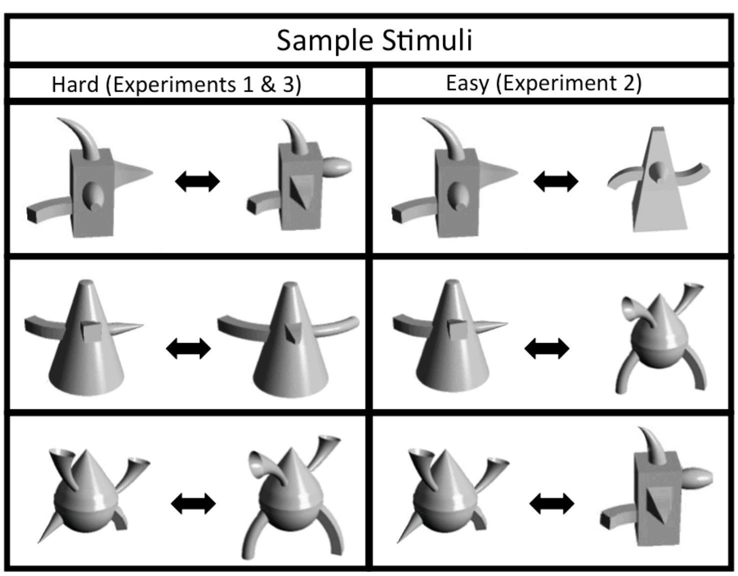

Figure 1: Sample identity morph pairs are shown for each of the three experiments. Pairs would be presented sequentially during different identity trials. Experiment 1 & 3 morphs (left panel) were drawn from the same morph family. Experiment 2 morphs (right panel) were the same as those of Experiments 1 & 3, but rearranged such that each morph pair included morphs from different families, and were therefore easier to differentiate.

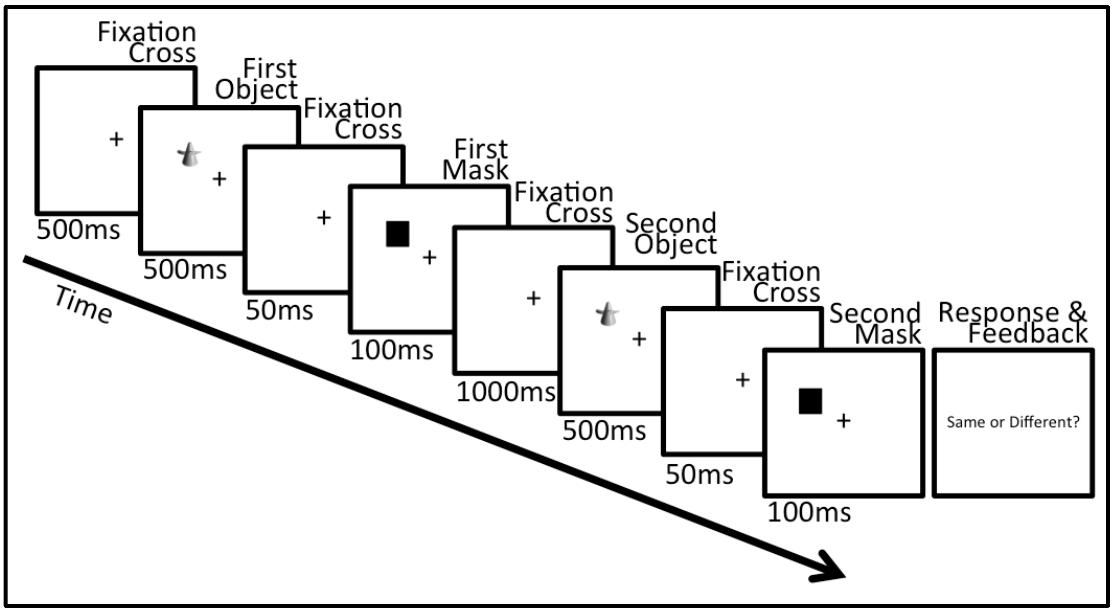

Figure 2: A sample trial from Experiment 1 is illustrated. While fixating on a central cross, subjects were presented with two objects sequentially. Objects could be of the same or different identity (relevant feature), and at the same or different location (irrelevant feature). Afterwards, subjects were asked to judge if they were of the same or different identity. They then received feedback: “Correct!” or “Incorrect!”

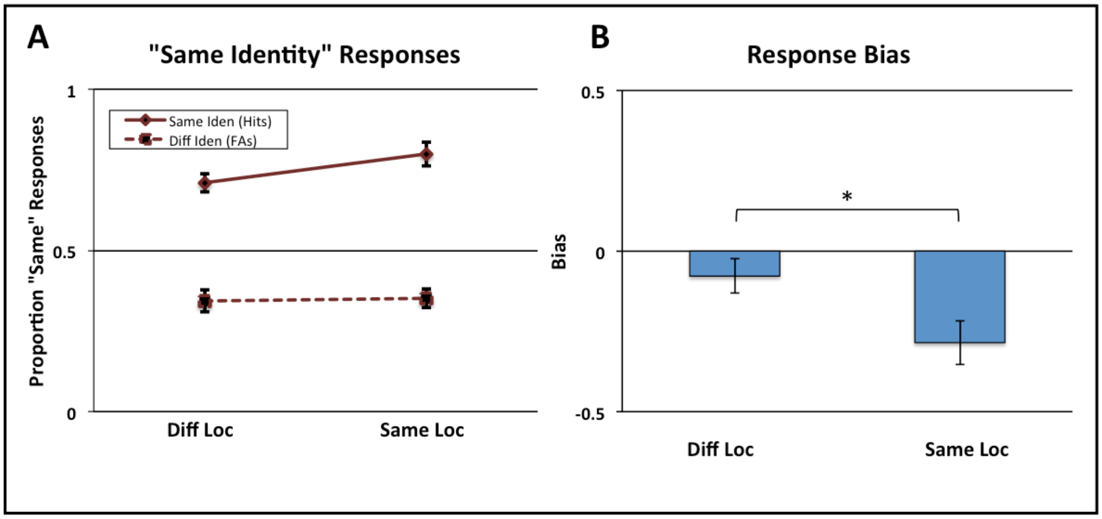

Figure 3: (A) For Experiment 1, proportion of "same" identity responses, separated by identity and location conditions. Solid line shows hits (correctly identified same identity), and dashed line shows false alarms (FAs; actually different identity). Error bars shown within-subject standard error of mean. Chance is 50%. (B) For Experiment 1, response bias for the identity task shown for same and different location trials. More negative values indicate a greater likelihood to respond "same" identity. Error bars show standard error of mean. Asterisk indicates significance ($p < 0.05$) for paired t test comparing location conditions, indicating a significant spatial congruency bias.

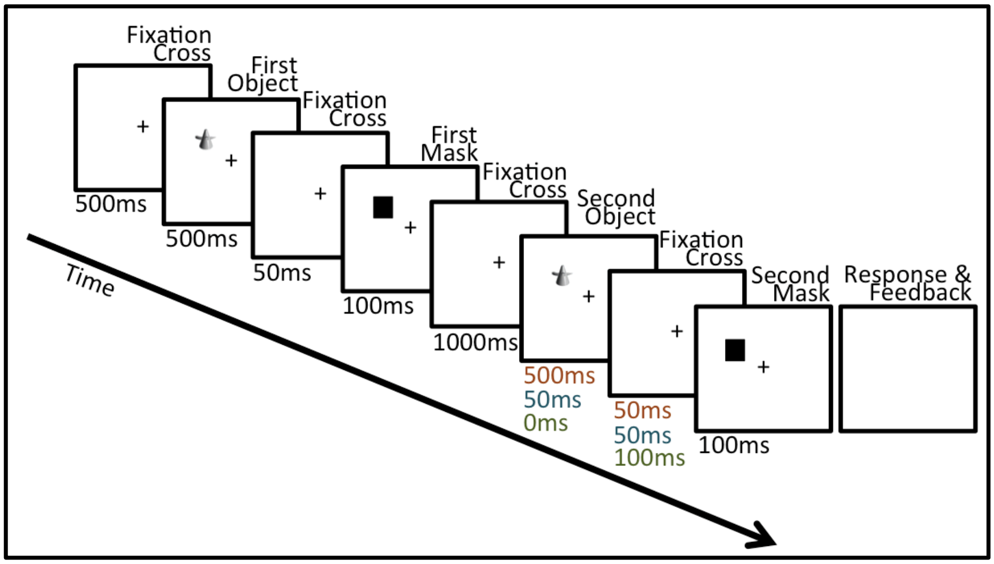

Figure 4: A sample trial from Experiment 2 is illustrated. While fixating on a central cross, subjects were presented with two objects sequentially. Objects could be of the same or different identity (relevant feature), and at the same or different location (irrelevant feature). Unlike Experiment 1, stimulus presentation time for the second image was varied: 500ms (like Experiment 1; orange), 50ms (blue), or 0ms (control trials; green). To account for different fixation times, presentation of following fixation cross was varied accordingly. Afterwards, subjects were asked to judge if they were of the same or different identity. They then received feedback (e.g. “Correct, they were same!” or “Incorrect, they were same!”).

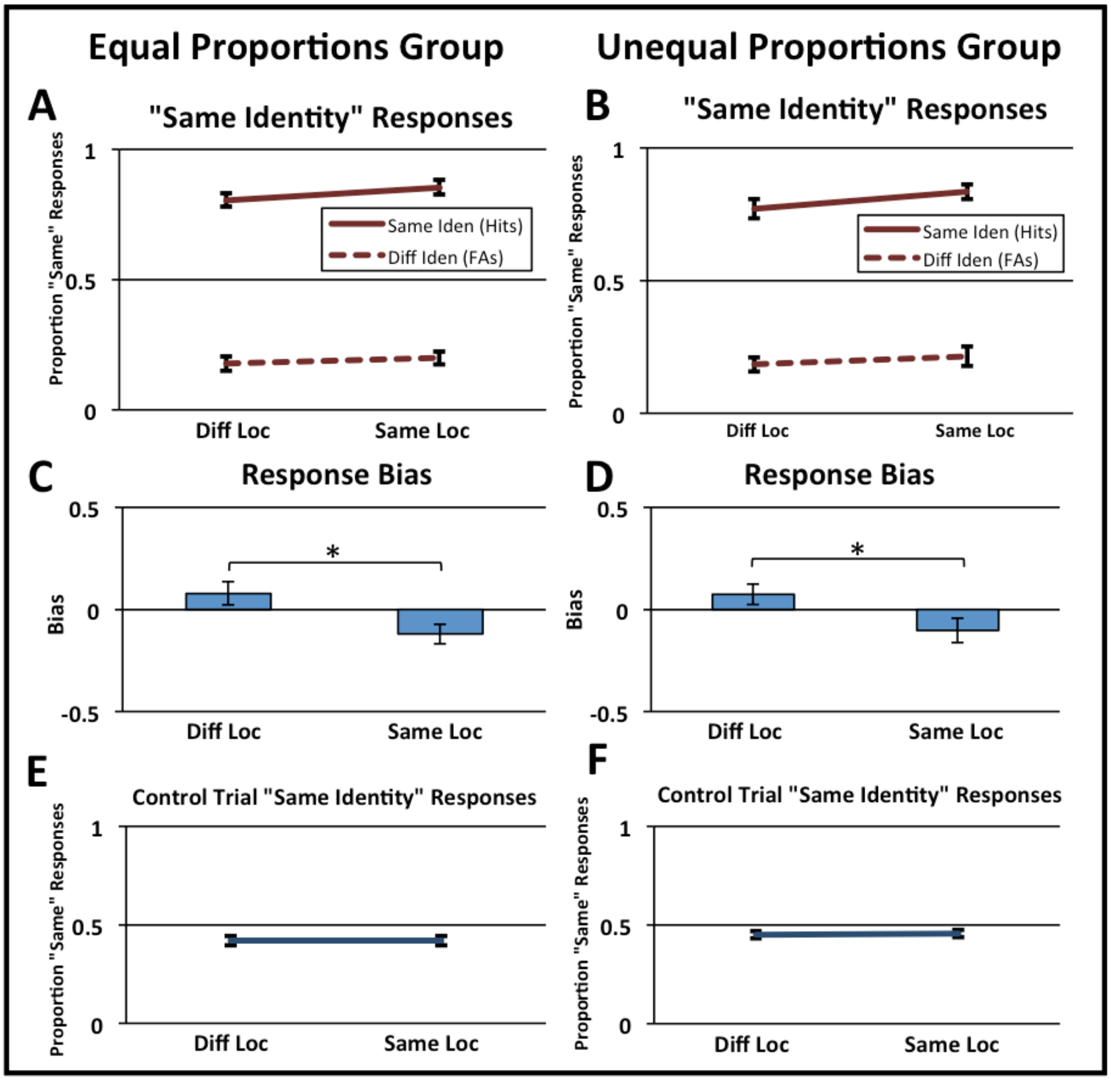

Figure 5: (A&B) Proportion of "same" identity responses, separated by identity and location conditions. Solid line shows hits (correctly identified same identity), and dashed line shows false alarms (FAs; actually different identity). Error bars shown within-subject standard error of mean. Chance is 50%. Graph A shows results for Experiment 2 group with equal proportions, and Graph B shows results for Experiment 2 group with unequal proportions. (C&D) Response bias for the identity task shown for same and different location trials. More negative values indicate a greater likelihood to respond "same" identity. Error bars show standard error of mean. Asterisk indicates significance ($p < 0.05$)

for paired t test comparing location conditions, indicating a significant spatial congruency bias. Graph C shows results for Experiment 2 group with equal proportions, and Graph D shows results for Experiment 2 group with unequal proportions. (E&F) Proportion of "same" identity responses on control trials, separated by identity and location conditions. Error bars shown within-subject standard error of mean. Chance is 50%. Graph E shows results for Experiment 2 group with equal proportions, and Graph F shows results for Experiment 2 group with unequal proportions.

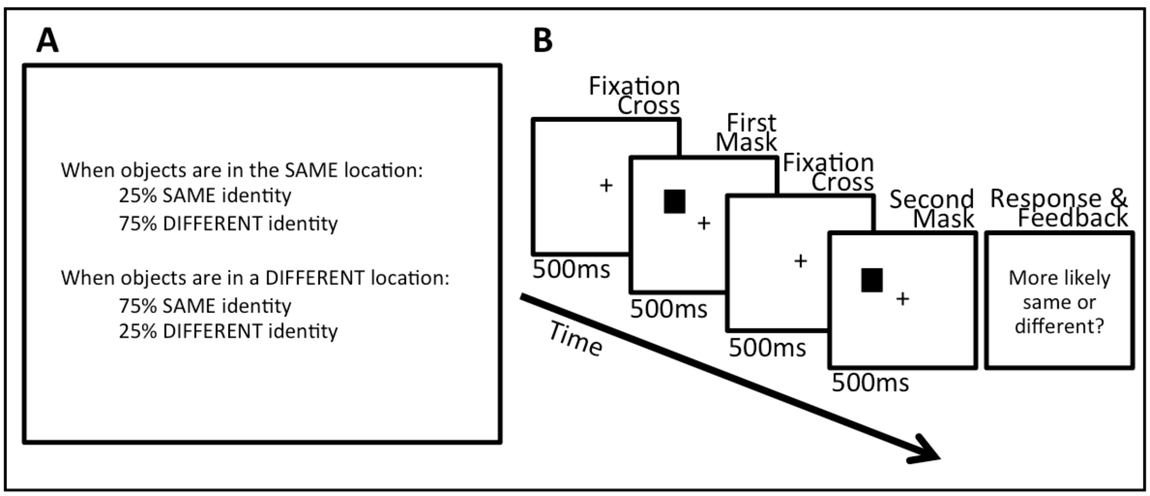

Figure 6: (A) Screen providing subjects with explicit information of proportions of trial conditions. (B) A sample "test trial" from Experiment 3's practice session is illustrated. After being informed of trial proportions, subjects were presented with two masks sequentially. Masks could be in the same or different location. Afterwards, subjects were asked to judge, if they were actual objects rather than masks, whether they were more likely to be of the same or different identity (based upon the location of the masks and provided percentages). After completing this instruction and practice session, subjects completed the main Experiment 3 task, which was identical to Experiment 1 (Figure 2).

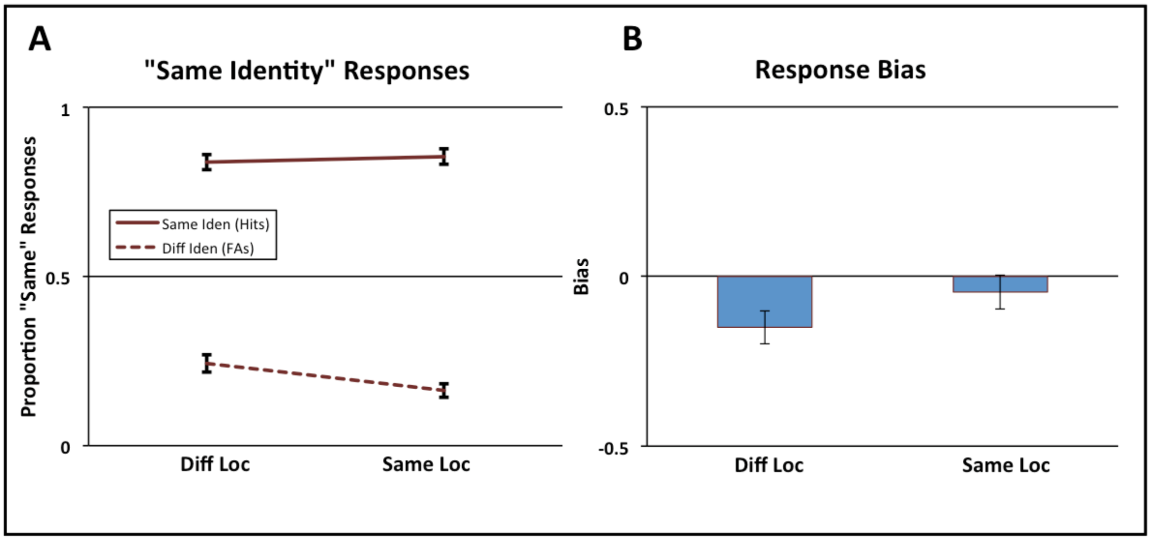

Figure 7: (A) For Experiment 3, proportion of "same" identity responses, separated by identity and location conditions. Solid line shows hits (correctly identified same identity), and dashed line shows false alarms (FAs; actually different identity). Error bars shown within-subject standard error of mean. Chance is 50%. (B) For Experiment 3, response bias for the identity task shown for same and different location trials. More negative values indicate a greater likelihood to respond "same" identity. Error bars show standard error of mean. Paired t test comparing location conditions did not find significant spatial congruency bias.

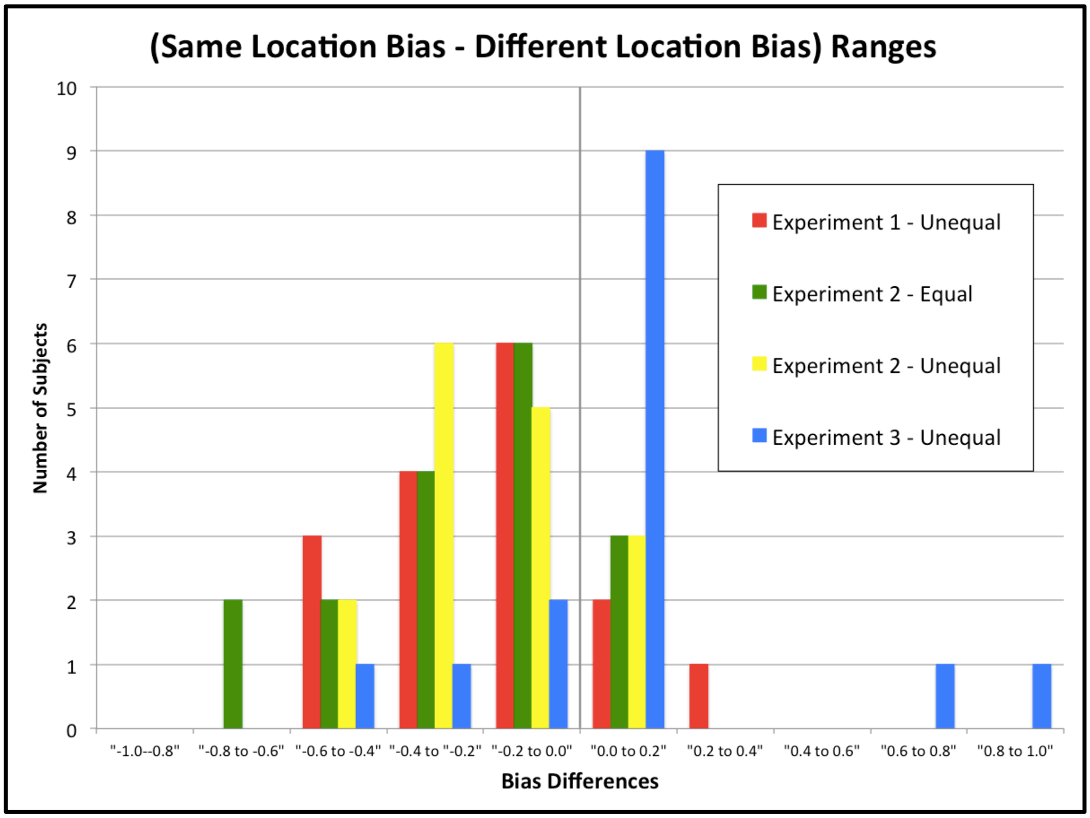

Figure 8: Histogram of individual measures of spatial congruency bias (bias differences) across all experiments. Bias difference calculated by subtracting different location bias from same location bias for each subject. Negative value indicates subjects more likely to report "same" identity when objects were in the same location compared to different locations. Positive value indicates subjects more likely to report "same" identity when objects were in different locations compared to the same location. Bin width is 0.2, and span range of -0.8 to 1.0.

Experiment 1		**Same Loc**	**Diff Loc**	**Iden Effect (rel dim)**	**Loc Effect (irrel dim)**
RT (s)	**Same Iden**	**0.389**	**0.399**	**p = 0.943**	**p = 0.004**

	Diff Iden	0.364	0.425		
Accuracy	Same Iden	0.799	0.710	p = 0.015	p = 0.003
	Diff Iden	0.649	0.657		
p("Same")	Same Iden	0.799	0.710	p = 0.003	p = 0.011
	Diff Iden	0.351	0.343		
d-prime		1.402	1.039	--	p = 0.001
Bias		-0.285	-0.078	--	p = 0.003

Experiment 2 - Equal		Same Loc	Diff Loc	Iden Effect (rel dim)	Loc Effect (irrel dim)
RT (s)	Same Iden	0.450	0.474	p = 0.716	p = 0.007
	Diff Iden	0.455	0.474		
Accuracy	Same Iden	0.853	0.804	p = 0.525	p = 0.241
	Diff Iden	0.800	0.822		
p("Same")	Same Iden	0.853	0.804	p < 0.001	p = 0.008
	Diff Iden	0.200	0.178		
d-prime		2.086	1.963	--	p = 0.234
Bias		-0.120	0.078	--	p = 0.005
Control RT (s)		0.763	0.768	--	p = 0.754
Control		0.420	0.420	--	p = 0.997

p("Same")					

Experiment 2 - Unequal		Same Loc	Diff Loc	Iden Effect (rel dim)	Loc Effect (irrel dim)
RT (s)	Same Iden	0.482	0.472	p = 0.784	p = 0.689
	Diff Iden	0.472	0.490		
Accuracy	Same Iden	0.835	0.770	p = 0.944	p = 0.174
	Diff Iden	0.786	0.815		
p("Same")	Same Iden	0.835	0.770	p < 0.001	p = 0.002
	Diff Iden	0.214	0.185		
d-prime		2.022	1.848	--	p = 0.081
Bias		-0.103	0.074	--	p = 0.001
Control RT (s)		0.710	0.708	--	p = 0.883
Control p("Same")		0.457	0.451	--	p = 0.742

Experiment 3		Same Loc	Diff Loc	Iden Effect (rel dim)	Loc Effect (irrel dim)
RT (s)	Same Iden	0.467	0.468	p = 0.007	p = 0.087
	Diff Iden	0.417	0.448		
Accuracy	Same Iden	0.855	0.839	p = 0.008	p < 0.001

	Diff Iden	**0.837**	**0.756**		
p("Same")	**Same Iden**	**0.855**	**0.839**	**$p < 0.001$**	**$p = 0.221$**
	Diff Iden	**0.163**	**0.244**		
d-prime		**2.168**	**1.794**	**--**	**$p < 0.001$**
Bias		**-0.046**	**-0.150**	**--**	**$p = 0.237$**

Table 1: Mean measures of RT(s), accuracy, and proportion of "Same" responses are shown for each condition (SISL, SIDL, DISL, and DIDL) for all three experiments. P-values from ANOVA F-tests (for RT, accuracy, p("same")) and paired t tests (for d-prime and bias) are given. For Experiment 2, p-values from paired t tests for control trial RT and p("Same") are also given. Experiment 1 has $N = 16$, Experiment 2-Equal has $N = 17$, Experiment 2-Unequal has $N = 16$, and Experiment 3 has $N = 16$.

Post-Q range of responses: In hindsight, does this [manipulation] seem accurate?
(subject correctly stated manipulation) "It wasn't obvious since I wasn't focusing on it"
"Yes"
"Makes sense they would try to trick you"
"[same identity at same location] was at the top of my mind"
"I realized I got a lot of them wrong"
"No"
"I realized near the end"
"Maybe"

“Makes sense”
“It was not obvious, 50/50”
“Makes more sense”
“Not very sure”

Table 2: Sample of varied responses to final post-question from Experiment 1. After being explicitly informed of the manipulation, subjects were asked: “In hindsight, does this [manipulation] seem accurate?” Responses were collected verbally, and may not be verbatim.

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